

UNITED STATES PATENT APPLICATION FOR:

HIGH PRESSURE BARRIER TO OIL LOSS BY DIFFUSION

INVENTORS:

DANIEL D. DITTMER

ALEXANDER PARKHOMOVSKY

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Signature

Peter L. Brewer
Name

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MOSER, PATTERSON & SHERIDAN, LLP
3040 Post Oak Blvd., Suite 1500
Houston, T xas 77056
Phon : (713) 623-4844
Fax: (713) 623-4846

HIGH PRESSURE BARRIER TO OIL LOSS BY DIFFUSION

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] This new application for letters patent claims priority from an earlier-filed provisional patent application entitled "High Pressure Barrier to Oil Loss by Diffusion." That application was filed on April 21, 2003 and was assigned Application No. 60/464,482.

BACKGROUND OF THE INVENTION

Field of the Invention

[0002] The present invention relates to fluid dynamic bearing motors. More specifically, the present invention pertains to fluid dynamic bearing motors such as are used to support and rotationally drive one or more memory discs.

Description of the Related Art

[0003] The computer industry employs magnetic discs for the purpose of storing information. This information may be stored and later retrieved using a disc drive system. Computer systems employ disc drive systems for transferring and storing large amounts of data between magnetic discs and the host computer. The magnetic discs are typically circular in shape (though other shapes are known), and are comprised of concentric, or sometimes spiraled, memory tracks. Each track contains magnetic data. Transitions in the magnetic data are sensed by a magnetic transducer known as a read/write head. The transducer is part of the disc drive system, and moves radially over the surface of the disc to read and/or write magnetic data.

[0004] **Figure 1** presents a perspective view of magnetic media **10** as are commonly employed for information storage. In this view, a plurality of stacked magnetic discs **10'** is shown. The discs **10'** in **Figure 1** are shown in vertical alignment as is common within a disc drive system. Each disc **10** has a central concentric opening **5** for receiving a spindle (shown at **51** in **Figure 2**). A rotary

motor drives the spindle **51**, causing the discs **10** of the disc pack **10'** to rotate in unison.

[0005] In operation, information stored in the magnetic layer of the disc **10** is read by a magnetic head assembly. The magnetic head assembly is part of a disc drive system, such as the system **50** shown in **Figure 2**. **Figure 2** presents a top view of an exemplary disc drive system **50**, with the magnetic head assembly seen at **58**. The disc drive assembly **50** includes a servo spindle **52** and an actuator arm **54**. The servo spindle **52** is motorized to pivot about an axis **40**. More specifically, the servo spindle **52** is selectively positioned by a voice coil motor **57** which pivots the actuator arm **54**, causing the arm **54** to move through arc **42**. In this manner, the arm **54** can be positioned over any radial location "R" along the rotating disc surface.

[0006] The actuator arm **54** carries a flexure arm or "suspension arm" **56**. The suspension arm **56**, in turn, supports the magnetic head assembly **58** adjacent a surface of a disc **10**. The head assembly **58** defines a transducer that is capable of reading magnetic information from the magnetic layer of the disc **10**, or writing additional information on a reserved portion of the disc **10**. The magnetic head **58** is typically placed on a small ceramic block, also referred to as a slider. The slider is aerodynamically designed so that it "flies" over the disc **10** as the disc is rotated at a high rate of speed.

[0007] As noted, the disc **10** itself is supported on a drive spindle **51**. The drive spindle **51** rotates the disc **10** relative to the magnetic head assembly **58**. **Figure 3** provides a perspective view of a disc drive assembly **50**. In this arrangement, a plurality of discs **10'** are stacked vertically within the assembly **50**, permitting additional data to be stored, read and written. The drive spindle **51** receives the central openings **5** of the respective discs **10**. Separate suspension arms **56** and corresponding magnetic head assemblies **58** reside above each of the discs **10**. The assembly **50** includes a cover **30** and an intermediate seal **32** for providing an

air-tight system. The seal **32** and cover **30** are shown exploded away from the disc stack **10'** for clarity.

[0008] In operation, the discs **10** are rotated at high speeds about axis **45** (seen in **FIG. 2**). As the discs **10** rotate, the air bearing slider on the head **58** causes the magnetic head **58** to be suspended relative to the rotating disc **10**. The flying height of the magnetic head assembly **58** above the disc **10** is a function of the speed of rotation of the disc **10**, the aerodynamic lift properties of the slider along the magnetic head assembly **58** and, in some arrangements, a biasing spring tension in the suspension arm **56**.

[0009] Each disc **10** has a landing zone **11** where the magnetic head assembly **58** lands and rests when the disc drive **50** is turned off. When the disc drive assembly **50** is turned on, the magnetic head **58** "takes off" from the landing zone **11**. Each disc **10** also has a data zone **17** where the magnetic head **58** flies to magnetically store or read data.

[0010] As noted, the servo spindle **52** pivots about pivot axis **40**. As the servo spindle **52** pivots, the magnetic head assembly **58** mounted at the tip of its suspension arm **56** swings through arc **42**. This pivoting motion allows the magnetic head **58** to change track positions on the disc **10**. The ability of the magnetic head **58** to move along the surface of the disc **10** allows it to read data residing in tracks along the magnetic layer **15** of the disc. Each read/write head **58** generates or senses electromagnetic fields or magnetic encodings in the tracks of the magnetic disc as areas of magnetic flux. The presence or absence of flux reversals in the electromagnetic fields represents the data stored on the disc.

[0011] In order to accomplish the needed rotation of discs, an electric motor is provided. The electric motor is commonly referred to as a "spindle motor" by virtue of the drive spindle **51**, or "hub," that closely receives the central opening **5** of a disc **10**. **Figure 4** illustrates the basic elements of a known spindle motor design, in cross-section. The motor **400** first comprises a hub **410**. The hub **410** includes an outer radial shoulder **412** for receiving a disc (not shown in **FIG. 4**). The hub **410**

also includes an inner shaft **414**. In this arrangement, the shaft **414** resides and rotates on a stable counterplate **440**. A sleeve **420** is provided along the outer diameter of the shaft **414** to provide lateral support to the shaft **414** while it is rotated.

[0012] It can be seen that a bearing surface **422**, or "journal surface," is formed between the shaft **410** and the surrounding sleeve **420**. In early arrangements, one or more ball bearing systems (not shown) was incorporated into the hub **410** to aid in rotation. Typically, one of the bearings would be located near the top of the shaft, and the other near the bottom. A raceway would be formed in either the shaft or the sleeve for holding the plurality of ball bearings. The bearings, in turn, would be lubricated by grease or oil. However, various shortcomings were realized from the mechanical bearing system, particularly as the dimensions of the spindle motor and the disc tracks became smaller. In this respect, mechanical bearings are not always scaleable to smaller dimensions. More significantly, in some conditions ball bearings generate unwanted vibrations in the motor assembly, causing the read/write head to become misaligned over the tracks. Still further, there is potential for leakage of grease or oil into the atmosphere of the disc drive, or outgassing of the components into this atmosphere.

[0013] In response to these problems, hydrodynamic bearing spindle systems have been developed. In these types of systems, lubricating fluid is placed along bearing surfaces defined around the rotating spindle/hub. The fluid may be in the form of gas, such as air. Air is popular because it avoids the potential for outgassing of contaminants into the sealed area of the head disc housing. However, air cannot provide the lubricating qualities of oil or the load capacity. Further, its low viscosity requires smaller bearing gaps and, therefore, higher tolerance standards to achieve similar dynamic performance. As an alternative, fluid in liquid form has been used. Examples include oil and ferro-magnetic fluids. A drawback to the use of liquid is that the liquid lubricant should be sealed within the bearing to avoid leakage. Any loss in fluid volume results in a reduced bearing load capacity and life for the motor. In this respect, the physical surfaces of the spindle and of the housing would come

into contact with one another, leading to accelerated wear and eventual failure of the bearing system.

[0014] Returning back to **Figure 4**, the motor **400** of **Figure 4** represents a hydrodynamic bearing system. A thrust plate **430** is disposed between the shaft **414** and the surrounding sleeve **420**. Fluid is injected in gaps maintained between the shaft **414** and surrounding parts, e.g., the counterplate **440**, the sleeve **420**, and the thrust plate **430**. The fluid defines a thin fluid film that cushions relative movement of hub parts.

[0015] The motor **400** is actuated by energizing coils in a stator in cooperation with one or more magnets. In the view of **Figure 4**, magnets **450** are seen disposed within the hub **410**, while stator coils **452** are provided on a base **460**. The magnets **450** and stator coils **452** interact to provide rotational movement of the hub **410**.

[0016] Additional details of fluid dynamic bearing systems are provided in U.S. Patent Application No. 10/099,205 filed March 13, 2002, and entitled "Low Power Fluid Dynamic Bearing." That application is commonly owned with the present application, and is incorporated herein in its entirety by reference. Of interest, that application presents various hydrodynamic motor designs wherein a thrust plate **430** is not employed.

[0017] As noted, it is important to retain fluid within the bearing surfaces for a hydrodynamically operated spindle motor. Various architectures have been proposed for retaining fluid within the bearing surfaces. Certain patents present a mechanical seal. For example, U.S. Patent 5,347,189 entitled "Spindle Motor with Labyrinth Sealed Bearing" provides a labyrinth seal outside one of the bearings. The labyrinth seal has two parts that mate to form a tortuous flow path for fluids. This serves to inhibit the escape of grease from ball bearings. U.S. Patent 5,925,955 entitled "Labyrinth Seal System" provides an alternative seal system for an electronic spindle motor.

[0018] Other patents provide for a grooved pattern that serves to retain fluid within a spindle motor. U.S. Patent 6,149,159 entitled "High Pressure Boundary Seal" provides for a "herringbone pattern" of grooves along or adjacent the outer surface of the shaft. A zone of high pressure is created at or about the center of the pattern, thereby creating a high pressure boundary seal. This, in turn, prevents the flow of lubricating fluid from the interior of the motor or the bearing into the interior section of the disc drive housing. Another example is U.S. Patent 5,533,812 entitled "Single Plate Hydrodynamic Bearing with Self-Balanced Fluid Level," which offers a thrust plate having grooved surfaces.

[0019] Still another means for retaining fluid within a hydrodynamically operated bearing surface for a spindle motor is presented in U.S. Patent 5,524,986. This patent is entitled "Fluid Retention Principles for Hydrodynamic Bearings." A flexible membrane is provided at one end of the fluid gap. The spring force of the membrane allows the gap volume to adjust with fluid changes as temperature fluctuates. In this respect, the membrane is flexible, and absorbs any increase in volume of the bearing fluid. The '986 patent also introduces the principle of a capillary seal. In this respect, a capillary seal is provided at one end of the gap. The capillary seal design helps retain a volume of lubricant oil within the system necessary for continuous motor operation.

[0020] One problem presented with the capillary seal design is that an end of the bearing gap is exposed to the ambient environment of the disc drive housing. This, in turn, can lead to a slow but progressive oil loss by evaporation. The lubricant oil is selected to have a low vapor pressure to reduce evaporation. Nevertheless, over the life of the motor a noticeable amount of lubricant is lost from the capillary seal by evaporation, as well as from vapor diffusion in the gas phase.

[0021] To compensate for the oil loss, the capillary seal dimensions are designed to hold a larger amount of oil than would otherwise be necessary. However, the available reservoir volume is limited by geometrical size constraints and by requirements for seal splash robustness during shock events.

[0022] Thus, a need exists for an improved fluid dynamic bearing system for a spindle motor that retains liquid within and along the bearing surfaces. Further, there is a need for such a motor that minimizes oil loss due to evaporation. Still further, there is a need for such a motor that minimizes the amount of oil that is lost from the capillary seal over the life of the motor.

SUMMARY OF THE INVENTION

[0023] The present invention provides an improved motor arrangement. The arrangement is useful in connection with rotary electrical motors, such as spindle motors in disc drive systems. More specifically, the invention is most applicable to motors that employ fluid dynamic bearing surfaces between relatively rotating parts.

[0024] In an exemplary arrangement, the improved spindle motor first comprises a hub having a shaft portion and an upper horizontal body portion. The motor also comprises a sleeve surrounding the shaft portion of the hub. A first fine gap is retained between the shaft and the inner diameter of the surrounding sleeve. In addition, a second fine gap is provided between the upper hub portion and the top of the sleeve. The first gap typically is substantially vertical, and is filled with a lubricating liquid, such as a clean oil. The second gap is typically horizontal. However, the present invention is intended to cover any relative angle between the first and second gaps.

[0025] A capillary seal is provided in the vertical fluid gap at one end. Preferably, the capillary seal is disposed at an upper end of the shaft proximal to the upper hub portion. In addition, air pumping grooves are machined along the horizontal fluid gap. The air pumping grooves may be machined into the bottom of the upper hub portion; preferably, though, they are machined into the top of the sleeve. The air pumping grooves are used to create a high pressure region in the vicinity of the capillary seal. In this respect, the high pressure barrier reduces the number of oil molecules diffusing out of the capillary seal and, therefore, the total oil loss from the system.

BRIEF DESCRIPTION OF THE DRAWINGS

[0026] So that the manner in which the above recited features of the present invention can be understood in detail, a more particular description of the invention, briefly summarized above, may be had by reference to the appended drawings. It is to be noted, however, that the appended drawings (Figures 5-8) illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope.

[0027] Figure 1 demonstrates a perspective view of magnetic media, i.e., thin film magnetic discs, as are commonly employed for information storage. In this view, a plurality of stacked discs is shown.

[0028] Figure 2 presents a top view of an exemplary disc drive assembly.

[0029] Figure 3 illustrates a perspective view of an exemplary disc drive assembly as might employ the improved spindle motor arrangement of the present invention.

[0030] Figure 4 provides a cross-sectional view of a hydrodynamic bearing spindle motor arrangement known as of the present filing.

[0031] Figure 5 presents a cross-sectional view of an improved spindle motor arrangement in which air pumping grooves are machined.

[0032] Figure 6 illustrates an enlarged view of the gaps formed between the shaft of the spindle motor of Figure 5, and the surrounding sleeve. Here, the grooves are provided on an upper surface of the sleeve.

[0033] Figure 7 depicts a perspective view of an exemplary sleeve having air pumping grooves, in one embodiment.

[0034] Figure 8 provides an enlarged cross-sectional view of the gaps formed between the shaft of the spindle motor of Figure 5, and the surrounding sleeve, in an

alternate embodiment. Here, the air pumping grooves are disposed along the underside of the hub.

DETAILED DESCRIPTION OF THE INVENTION

[0035] The present invention provides an improved spindle motor arrangement. The improved motor employs novel air pumping grooves as a means for retaining liquid lubricant within a fluid bearing interface.

[0036] **Figure 5** presents a cross-sectional view of an improved spindle motor arrangement **500** in one embodiment in which air pumping grooves **526** are machined. The motor **500** first comprises a hub **510**. The hub **510** provides a radial shoulder **512** for receiving and supporting a body to be rotated, such as a magnetic disc (not shown). The hub **510** defines a central shaft portion **514** and a horizontal body portion **518**. The shaft **514** is configured for constant high speed rotation. This rotation is established by a stator **552** which is mounted from a base **560**. The stator **552** defines an electric coil that, when energized, creates a magnetic field. The energized coil cooperates with magnets **550** mounted from the inner surface of the hub **510** to generate rotational movement of the hub **510**.

[0037] As noted, the shaft **514** is configured for high speed rotation. In this respect, the shaft **514** rotates over a stationary counterplate **540**. The interface between the bottom of the shaft **514** and the top of the counterplate **540** thus defines a thrust bearing **542**. Fluid such as liquid lubricant is maintained along the thrust bearing gap **542** to provide a fluid bearing surface. One of the top face of the counterplate **540** or the bottom surface of the shaft **514** includes a grooved pattern (seen at **544** in the enlarged view of **Figure 6**). The grooved pattern assists in maintaining fluid between the shaft **514** and the counterplate **540** when the shaft **514** rotates. When the motor **500** is at rest, the shaft **514** presses directly on the counterplate **540**. Fluid is then at least partially pressed into the grooves **544**, and also extruded around the outer diameter of the shaft **514**.

[0038] The motor **500** of **Figure 5** next comprises a sleeve **520**. In the arrangement of **Figure 5**, the sleeve **520** is stationary and is supported on the counterplate **540**. The sleeve **520** is disposed between the rotating shaft **514** and shoulder **565** of the surrounding base **560**. It can be seen that the interface between the rotating shaft **514** and the surrounding sleeve defines a fluid bearing surface **522**. When the motor **500** is energized and the shaft **514** and connected hub **510** are rotated, lubricant is drawn downward from the sleeve bearing surface **522** into the thrust bearing surface **542**. Lubricating fluid is drawn into the thrust bearing gap **542** under the urging of the grooved pattern **544**. More specifically, the lubricating fluid is drawn into the thrust bearing region **542** to support relative rotation between the bottom end of the shaft **514** and the facing surface of the counterplate **540**, the fluid being maintained in part in the gap **542** by the grooved pattern during rotation. When the shaft **514** comes to rest, the shaft end will rest on the plate **540** and, although the volume of fluid is very small, it will tend to be forced back out into the sleeve bearing gap **522** between the shaft **514** and the sleeve **520**. Therefore, space is preferably allowed in this gap **522** for this fluid.

[0039] To prevent the shaft **514** and connected hub **510** from being displaced axially too far above the counterplate **540**, since this is an axially upward thrust bearing **542** between the shaft end and the counterplate **540**, an opposing bias is typically introduced. This bias is utilized to prevent the thrust bearing gap **542** from becoming too large, which would reduce the effectiveness of the motor **500**. Approaches to this can be seen in the provision of a biasing magnet **564** facing the motor magnet **550** and axially spaced therefrom. By selecting a suitable size and location for this magnet **564**, an appropriate bias against the shaft **514** being axially displaced too far from the counterplate **540** or the base **560** can be optionally introduced.

[0040] In the arrangement of **Figure 5**, the fluid gap **522** between the shaft **514** and the inner diameter of the surrounding sleeve **520** is essentially vertical. At the same time, the fluid gap **524** between the upper hub portion **518** and the top of the

sleeve **520** is essentially horizontal. However, the present invention is intended to cover any orientation and relative angle between the first **522** and second **524** gaps.

[0041] To inhibit the loss of liquid lubricant from the bearing gaps **542**, **522** during operation, a capillary seal **516** is provided at the distal end of the sleeve bearing gap **522** from the thrust bearing gap **542**. Further information concerning operation of a capillary seal within a bearing gap is disclosed in U.S. Patent 5,524,986 entitled "Fluid Retention Principles for Hydrodynamic Bearings." That patent issued to Seagate Technologies, Inc. in 1996.

[0042] To further inhibit the loss of fluid such as liquid lubricant from the bearing gaps **542**, **522**, particularly during operation of the motor **500**, novel pumping grooves **526** are provided. The pumping grooves **526** are positioned along an upper gap **524** between the horizontal body portion **518** of the hub **510** and the sleeve **520**. The pumping grooves **526** may be disposed along the surface of either the horizontal body portion **518** of the hub **510** or the sleeve **520**. Preferably, the grooves **526** are placed along the sleeve **520**. The pumping grooves pump fluid such as air.

[0043] **Figure 6** illustrates an enlarged view of gaps **522** and **524** formed between the hub **510** and the surrounding sleeve **520**. More specifically, gap **522** is formed between the shaft portion **514** of the hub **510** and the sleeve **520**, while gap **524** is formed between the top of the sleeve **520** and the lower surface of the central body portion **518** of the hub **510**. In this enlarged view, the capillary seal **516** can be seen in the sleeve bearing gap **522**. In addition, air pumping grooves **526** can be seen on a top surface of the sleeve **520**. The air pumping grooves **526** serve to inhibit the evaporation of oil. Operation of this inhibitor phenomenon is as follows.

[0044] When oil evaporates from the capillary seal **516** in a spindle motor, an oil vapor is released. This may occur during idle periods; however, it may also occur following periods of use when the overall motor system **500** heats up. As the temperature of the lubricating fluid, e.g., oil, rises, the lubricating fluid volume begins to expand. Ultimately, some oil begins to transition to gas phase and diffuses

outward past the capillary seal **516**. The resulting oil vapor typically saturates the region of the bearing gap **522** closest to the seal **516**. Given enough time to reach equilibrium, the entire volume around the seal **516** will become saturated with oil vapor unless the diffusion of molecules is not limited by tight gaps, or if the gap volume is too large to become fully saturated. An undesirable oil loss occurs when oil molecules migrate past the capillary seal region **516** and do not return.

[0045] An increase in air pressure in the volume adjacent to the capillary seal **516** will decrease the rate of oil molecule transfer to the outside of the capillary seal region **516**. Therefore, the rate of oil evaporation from the motor **500** can be reduced by using a "pump" to pressurize the region adjacent to the capillary seal **516**. The issue then becomes one of creating a pumping arrangement to increase air pressure along the gap **524** adjacent the capillary seal **516**.

[0046] According to the present invention, such a pump can be created by placing grooves in a tight gap region adjacent the capillary seal **516**. This is provided by placing the novel air pumping grooves **526** between the hub **518** and sleeve **520** or other motor component near the capillary seal **516**. In one arrangement, the grooves **526** are disposed along the bottom of the central hub portion **518** on a side of the capillary seal **516** opposite the counterplate **540** (see **Figure 8**). In another embodiment, and as shown in **Figure 6**, the grooves **526** may be disposed along the top surface of the sleeve **520**, also on a side of the capillary seal **516** opposite the counterplate **540**. In one embodiment, the horizontal gap **524** is approximately 0.16 millimeters in height. In one embodiment, a portion of the motor surfaces on top of the sleeve **520** and under the hub **518** along the horizontal gap **524** are pre-coated with a fluid repelling coating.

[0047] The groove pattern **526** is configured so that air flow is guided into the capillary seal area **516** when the hub **510** is rotated. An example of such a pattern is a spiral pattern machined into the top of the sleeve **520**. However, any type of pattern as is used to draw air in a tight gap region is suitable to serve as the air pumping groove.

[0048] **Figure 7** depicts a perspective view of an exemplary sleeve **520** having air pumping grooves **526**, in one embodiment. Preferably, the groove pattern **526** is spaced apart from the formed fluid meniscus of the capillary seal **516** and is not pre-coated in oil. As the sleeve **520** and the hub **510** rotate relative to one another, air is introduced by operation of the groove pattern, e.g., pattern **526**, in order to produce a high pressure region. Air is introduced into the upper gap region **524** between the horizontal hub portion **518** and the sleeve **520**. This produces a high pressure region along the capillary seal **516** opposite the bearing surfaces **522**, **542**. As the total pressure in the system is increased, there is a corresponding reduction of the gas phase diffusion coefficient of the oil through the reduction of the mean free path of the oil molecules. (This applies over a range of temperatures in the system, brought into the steady state condition with respect to oil diffusivity. This, in turn, reduces evaporation loss.

[0049] The diffusion of oil into the vapor phase is a function of the mean free path of the oil molecules in the gas phase versus the mean velocity of the oil molecules in the air. The general function is as follows:

$$[0050] \quad D = f(\lambda_{\text{mfp}}, \bar{v}) \quad (1)$$

[0051] The relationship can be mathematically defined. In the ideal gas approximation which can be applied in the range of pressures under consideration in the capillary seal system, the diffusion coefficient of the oil vapor is directly proportional to the mean free path of the oil molecules in the gas phase:

$$[0052] \quad D_{\text{oil}} = \frac{1}{3} \lambda_{\text{mfp}} \bar{v} \quad (2)$$

[0053] where

[0054] λ_{mfp} is the mean free path of the oil molecules in the vapor phase; and

[0055] \bar{v} is the mean velocity of the oil molecules in the gas phase.

PATENT

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[0056] The mean free path, λ_{mfp} , is proportional to system parameters, as follows:

$$[0057] \quad \lambda_{\text{mfp}} \propto \frac{k T}{p \sigma \sqrt{2}} \quad (3)$$

[0058] where k is the Boltzman gas constant;

[0059] T is the temperature in the system; and

[0060] σ is the molecular cross section of the oil.

[0061] Thus, pressurizing the capillary seal region by a certain factor will decrease the oil diffusion through air by the same factor.